The representation of definite descriptions

Dols, F.J.H.

Publication date:
1990

Document Version
Publisher's PDF, also known as Version of record

[redacted]

ITK RESEARCH REPORT

INSTITUTE FOR LANGUAGE TECHNOLOGY AND ARTIFICIAL INTELLIGENCE

INSTITUUT VOOR TAAL- EN KENNISTECHNOLOGIE

[redacted]

ITK Research Report
April 13, 1990

The Representation of Definite Descriptions

Frens J.H. Dols

No. 12

ISSN 0924-7807

Tilburg University, P.O.Box 90153, 5000 LE Tilburg, The Netherlands
Phone: +3113 663113, Fax: +3113 663110.

The Representation of Definite Descriptions

Frens J.H. Dols

Institute for Language Technology
and Artificial Intelligence (ITK)
Tilburg, The Netherlands
Earn: dols@kub.nl

ABSTRACT

In this paper augmented phrase structure rules are presented for singular and plural definite descriptions, including wh-phrases. For multi-noun phrase sentences and sentences with several wh-noun phrases, a general *cumulative* analysis is proposed and corresponding semantic rules are given. In this analysis presuppositions are not part of the semantic structure. The semantic rules are expressed in a many-sorted recursively typed higher-order λ-calculus. The choice of the rules has been guided by semantic and pragmatic considerations. The rules were to be acceptable from a computational point of view, e.g. for use in a dialogue system. The not so unusual 'singleton representation' for singular descriptions is rejected, and a ***bounded uniqueness operator*** is used, which is designed for use in a higher-order typed language. The use of this operator shows that a uniform representation is possible for such phrases as 'my plane', 'the ITK' and 'which flight', being in line with the Strawsonian rather than the Russell-Fregean solution.
Finally, the representations proposed are compared with the classical solutions of Russell, Frege and Strawson, and with a solution implemented in the TENDUM dialogue system.

Contents

1 Introduction

In this paper I introduce formal representations for unique and definite descriptions that allow for a robust treatment of the related problems in a dialogue system. In particular, if the uniqueness presupposition underlying a description is not satisfied, the control mechanism of a dialogue system must be able to generate a dialogue control act (Bunt 1988a) to the effect that the partner is informed of the apparent disagreement.
The proposal includes:

- the introduction of the syntax and semantics of a typed *bounded uniqueness operator* in the context of a higher-order typed representation language;
- a uniform treatment of singular unique and definite descriptions in terms of the uniqueness operator;
- the details of a *cumulative* analysis of plural multi-noun phrase sentences in an augmented phrase structure grammar (Discontinuous PSG; Bunt 1985; Bunt et al. 1987; Bunt 1988b);
- a wide scope analysis of definite wh-descriptions ('which plane') in which semantic rules are formulated for sentences with one or more wh-noun phrases.

The representations presented here are such that descriptions like 'John', 'the Kl402', 'the plane' and 'which flight' all have the same semantic structure: they all denote a unique object. In section 2, I present the details of the use of the uniqueness operator and a cumulative analysis of plural multi-noun phrase sentences including wh-noun phrases. In section 3 a comparison is made with the literature and with the solution implemented in the TENDUM dialogue system (Bunt et al. 1984). The use of a uniqueness operator brings within reach a phrase structure treatment of presuppositions (Dols 1990a) and of dialogue referents introduced by an utterance (Dols 1990b).

2 The correct treatment of descriptions

2.1 Unique and definite descriptions

In the following, I distinguish between unique and definite descriptions. Unique descriptions are phrases of which the referent is supposed to be unique *under all circumstances*. Examples are proper names like 'John' or a phrase like 'the Kl402'. Proper names are often called *rigid designators* and will be briefly discussed in section 2.3.8.

Definite descriptions have a unique referent with respect to *a certain context*. Examples of definite descriptions are 'the president of the US' or 'the plane' or 'which flight' in 'Which flight is due at 12:00?' and also plural descriptions like 'the planes' in 'The planes are due at 12:00'. They may be composed of several constituents like 'the Dutch flight', 'the first flight from Montreal' or 'The first flights that I can take tomorrow' or 'the board of the company'.

Because the denotation of definite descriptions depends upon the context, it is often specified in terms of an intensional (possible worlds) framework. In this paper representations are considered in an extensional language. This does not mean that contextual information cannot be taken into account, as I will show in the next paragraph.

A second presupposition of descriptions often mentioned in the literature is the existence *per se* of a referent. Depending upon the choice of the representation language both presuppositions may be formalized in different ways. For example, for the expression 'the Dutch flight' the predicate logical formula
$\exists$ **x: [Flight(x) $\wedge$ Dutch(x) $\wedge$ $\forall$ y: (Flight(y) $\wedge$ Dutch(y) $\rightarrow$ x=y)]**
is sometimes used (see also section 3.1). I will use a different representation in a more sophisticated representation language, suited for the semantic representation of natural language expressions (Bunt 1985). The following formula expresses that counting those flights that are Dutch gives the value 1:
COUNT(SELECT(Flights, λ x: Dutch(x))) = ONE.
In this paper only singular and plural descriptions are considered, with the ex-

clusion of mass and ground descriptions.

2.2 Descriptions and the lexicon

Unique and definite descriptions consist of a proper name or a definite article and a (complex) nominal phrase. The articles belong to the group of *central determiners* for reasons that will be explained in the next section where the structural syntactic and semantic analysis of descriptions is discussed.

The closed group of central determiners consists of articles, possessives, wh-determiners and demonstratives. Examples are 'the Kl402', 'the planes', 'my flight', 'which plane', 'that flight', 'these flights'.

Following Bunt (1985), central determiners have only one semantic representation in the lexicon, a constant Cr. The function constant Cr (*'Contextually Relevant'*) is a polymorphic characteristic function that is applicable to all kinds of denotations. Its denotation is defined in terms of the current context: applied to an argument it yields all relevant referents of the right type. Consequently, its meaning changes with the context of interpretation, as is in general true of nonlogical constants. There is also a nondynamic aspect to it in that *the way* the relevant objects are chosen does not change. Indeed, in an intensional framework it is exactly this nondynamic aspect that is formalized and taken to be its denotation.

2.3 Descriptions and the grammar rules

In this section I first give some rules for the syntactic analysis of descriptions. The details are partly based upon the rules used in Bunt (1985) and those implemented in the grammar component of the TENDUM dialogue system. As he is concerned primarily with various aspects of quantification of plurals and mass terms, Bunt devotes no attention to singular definite descriptions.
Second, the associated semantic rules are given.

2.3.1 Syntactic structure

Unique and definite descriptions belong to the syntactic category of noun phrases (NP). In a complex noun phrase three kinds of determiners may occur, each having their own semantic function, associated with their position:

Predeterminer + Central determiner + Postdeterminer + Noun

The set that is determined by the central determiner and the central noun of the description is called the *source*. For example, in the phrase 'All these four planes are tested' the central determiner 'these' plus the noun determines the source of quantification, the predeterminer 'all' indicates which fractions of the source are involved in the predication *being tested*, and the postdeterminer 'four' expresses a presupposition about the source. The predicate may apply to individual members or to groups of them, or to the source as a whole. An example is 'The books are heavy'. Wh-determiners like 'which' are also considered to be central determiners (see section 2.3.5).

This classification does not cover all kinds of determiners. Determiners like 'each' and 'some' are not central determiners, because they cannot be preceded by predeterminers (*all each children), nor do they belong to the group of predeterminers (*each the children) or postdeterminers (*these some children) - though 'each of' is a predeterminer. They are therefore classified as a distinct group, called DET. In this paper no rules concerning DET occur. The names of the syntactic categories for these four groups are PREDET, CENTRALDET, POSTDET and DET.

Plural and singular definite descriptions like 'the planes' or 'the flight' are constructed from a NPCENTRE, forming a noun phrase:

(1) NPCENTRE $\rightarrow$ NP.

A NPCENTRE consists of a central determiner and a (complex) nominal:

(2) CENTRALDET + NOM $\rightarrow$ NPCENTRE.

This rule applies to plural as well as to singular descriptions, although their semantic parts differ, as will be explained in the next section.

Singular NPCENTREs cannot be combined with predeterminers (*all my flight).

Plural descriptions including a predeterminer like 'all the flights' are constructed by the rule:

(3) PREDET + NPCENTRE → NP.

Numerical postdeterminers explicitly express a presupposition about the source. They do not restrict the denotation of the noun phrase. The rule that combines a postdeterminer and a noun thus takes over the semantic representation of the latter. I will not introduce sucha rule, because its semantic part is of less importance. For a treatment of the presupposition part of rules that include postdeterminers, see Dols (1990a).

Unique descriptions are constructed directly from a proper name or from a central determiner and a proper name, like 'the Kl402':

(4) PROPERNAME → NP,

(5) CENTRALDET + PROPERNAME → NP

'Real' proper names like 'John' cannot be combined with central determiners (*the John); here, the particular value of the gender feature (called *noval*) of these proper names precludes application of rule (5). Rule (5) can be replaced by an application of rule (2) above, followed by an application of rule (1) that lifts the NPCENTRE to a NP, provided there would be a rule lifting the proper name to a NOM. The number of rules would not be reduced by this, because the semantic structure of (5) and (2) differ, as I will demonstrate in the next section.

To summarize, plural descriptions are constructed from a NPCENTRE with or without a predeterminer ('all the flights', 'the flights'). Singular descriptions are constructed from a singular NPCENTRE ('the flight') or from a proper name with or without a CENTRALDET ('the Kl402', 'John').

2.3.2 Semantic structure

The semantic structures assigned to definite descriptions will **not** contain presuppositions. This choice is discussed in section 3, where a comparison is made with analyses that do include them. I do think that a grammar should generate representations of presuppositions, but they should not be part of the semantic representation. In Dols (1990a) I extend the rules used in this paper with a part that generates representations of presuppositions. In this way, the truth conditions of presuppositions do not interfere with those of the semantic representation.

The representation of the semantic structure of singular and plural wh-descriptions ('which flight', 'which planes') is given separate attention in sections 2.3.5, 2.3.6 and 2.3.7. Semantic representations of unique and singular as well as plural definite descriptions are given below. The semantics for rules (4) and (5) are given first, followed by the singular variants of rules (1) and (2). Subsequently, the plural variants of (1) and (2) are defined and finally the semantics for rule (3) with predeterminers is given.

2.3.3 Singular descriptions

The semantic representation assigned to noun phrases denotes the characteristic function of the set of all properties that are true of the nominal constituent. For example, 'the K1402' is represented as λ P: P(K1402). The sentence 'the K1402 arrives' is represented by applying the lambda expression to the predicate, which, after conversion, yields **Arrives(K1402)**. The semantic part of rules (4) and (5) thus is:

(4' and 5') λ P: APPLY(P, PROPERNAME')

where 'PROPERNAME'' denotes the semantic representation of the constituent 'PROPERNAME' . Note that the reference to the context, being the semantics of the CENTRALDET, is not part of the semantic structure of (5'). Indeed, the referent of complex unique descriptions is supposed to be unique under all circumstances (see section 2.1).

Singular definite descriptions also have this semantic structure. This means that the semantic part of the singular variant of rule (1) is:

(1' singular) λ P: APPLY(P, NPCENTRE')

The singular NPCENTRE' denotes the definite referent, to which the predicate

P is applied. I introduce a special operator that is used to denote single objects through a description, similar to the *iota operator* in a predicate logical language (Hilbert and Bernays 1970). Here, it is a *typed bounded uniqueness operator*, denoted by '!', that relates a set-denoting expression and a predicate expression. It does not introduce a variable but the predicate involved will usually be a lambda expression binding a variable.

The definition is given in the context of a typed higher-order language. The recursive types used here are the set type **S(t1)** denoting the *domain of all sets* of elements in the domain of type **t1**, and the predicate type (**t2** $\rightarrow$ **tv**), denoting the *domain of all functions* from the domain denoted by t2 to the domain of truth values. The formal requirement **Overlap(t1, t2)**, ensures that the domains of **t1** and **t2** have elements in common. It states that **t1** and **t2** are either identical atomic types or complex types having at least one component in common. (For the notion of type component see Bunt (1985:305). In the definition below, E and P are supposed to be expressions of the typed higher-order language.

Syntax of the uniqueness operator

If E is an expression of type S(t1) and P of type (t2 $\rightarrow$ tv) and Overlap(t1,t2) with overlapping type t3, then !(E, P) is an expression of type t3.

Semantics of the uniqueness operator

The denotation of !(E, P) is the only element of the denotation of E for which the predicate P yields true. If there is no such element or if there are more, the denotation is undefined.

The semantics of a singular definite description as defined by rule (2) may now be expressed in terms of the uniqueness operator:

(2' singular) !(NOM', λ x: CENTRALDET'(x))

where NOM' and CENTRALDET' represent the semantics of the constituents. As explained in section 2.2, CENTRALDET' is always the constant Cr, a function that selects all contextually relevant objects of the right type.

Here is an example of the result of applying rule (2' singular) to 'the plane':
!(Planes, λ x: APPLY(Cr, x))
denotes *the one plane that is contextually relevant.* Compare this with the expression denoting the set of all planes that are contextually relevant:
SELECT(Planes, λ x: APPLY(Cr, x)).
Applying rule (1' singular) to the result of rule (2' singular) gives (somewhat simplified):
λ P: P(!(Planes, Cr)).
Applying this function to the representation of the verb in 'The plane arrives' gives, after conversion:
Arrives(!(Planes, Cr)).

2.3.4 Plural definite descriptions

In plural definite descriptions the elements of the referent may be involved in a more complex way. In section 2.3.1 I have explained that the central determiner together with the noun denotes the source. The predicate associated with a description may apply to individual members of the source, to groups of them, or to the source as a whole. The set to which the predicate is applied, is called the *domain*. The domain is derived from the source by a *distribution function* (Bunt 1985:156). The semantic representation of plural descriptions is rather complicated due to the representation of various ways of distribution. I will use a formula consisting of a distribution function applied to the source *and the predicate*: DISTRIBUTION(S, P). It denotes the set of (groupings of) elements of S for which P holds; that is, it denotes the quantification *involvement* rather than the quantification *domain*.

A noun phrase like 'the flights' expresses complete source involvement, as does the predeterminer in 'all the flights'. Therefore, in this restricted fragment, both rules for constructing plural noun phrases have the same semantic structure, although derived in a different way. The semantics of the predeterminer expresses complete source involvement while the semantics of the NPCENTRE provides the source. When there is no predeterminer, the semantic part of rule (1), which lifts the NPCENTRE to a noun phrase, provides the representation of the complete involvement.

The operation $\bigcup^*$ ('UNION STAR', Bunt 1985), used in the following representations, flattens the set of objects for which the predicate holds; the involvement may consist of elements, as well as subsets of the source (in case of unspecific predication, Bunt 1985, p. 149). In order to count the involved source elements the involvement must be flattened. The flattening operation is well known as a *list operation* in LISP ('SQUASH', Winston and Horn 1984:343) and a *list predicate* in PROLOG environments ('FLATTEN', Sterling and Shapiro 1986:135-137). The recursive processes of these operations stop when an atomic element ('token') is recognized.

The logical constant 'UNION STAR', however, denotes a *set operation*. defined with respect to the complexity of the elements in the source. These elements may be sets containing sets (etc.) to which a higher-order predicate is applied; the elements of these nested sets in the source should not be counted as being involved. This means, that sets also occurring in the source must not be 'flattened'. The operations mentioned above, however, flatten until a token is recognized. In order to recognize sets of source elements in the involvement, the expression denoting the source is an argument of the operator. The types of sets that are to be 'flattened' are compared with the types of the elements in the source. Sets with the same type structure as the elements in the source are not flattened. In this way, the test does not involve extensive computation. Thus, 'UNION STAR' is defined with respect to the complexity of the elements in the source.

The semantic part of the plural instance of rule (1) expresses complete source involvement (in terms of equality) and accounts for the possible distribution of a predicate P that may become associated:

λ P: (NPCENTRE' = $\cup$*(NPCENTRE', DISTRIBUTION(NPCENTRE', P)))

For example, the sentence 'the chairs are lifted' is (after conversion) represented as

SELECT(Chairs, Cr) = $\cup$* (SELECT(Chairs, Cr), DISTRIBUTE(SELECT(Chairs, Cr), Lifted)))

I will use a slightly different representation of the complete involvement of the source:

(1' plural) λ P: FORALL(NPCENTRE', λ x: x $\in$ $\cup$*(NPCENTRE', DISTRIBUTION(NPCENTRE', P)))

When applied to a predicate this formula expresses (in terms of $\in$) that, regardless of the way the elements of the source are related to the predication, **all** elements are involved. For example, the sentence 'The chairs are lifted' is represented as

FORALL(SELECT(Chairs, Cr), λ x: x $\in$ $\cup$* (SELECT(Chairs, Cr), DISTRIBUTE(SELECT(Chairs, Cr), Lifted)))

This means that all chairs that are contextually relevant, are involved in the process of lifting, regardless of the way in which they are lifted, be it individually, collectively or in groups.

The semantic structure for the plural variant of rule (2) of the previous paragraph denotes the source:

(2' plural) SELECT(NOM', λ x: CENTRALDET'(x))

This means that the semantics for 'the planes' denotes the set of relevant planes:

SELECT(Planes, λ x: Cr(x))

Thus, the logical constant 'SELECT' is to plural descriptions what the ! operator is to singular ones.

The semantic structure of rule (3), which combines a predeterminer with a NPCENTRE (except those with a wh-determiner), is based upon the semantic structure of (1' plural). The semantics of the predeterminer is derived by abstraction over the NPCENTRE. The representation for the predeterminer thus is:

λ X: λ P: (X = $\bigcup^*$(X, DISTRIBUTION(X, P))

or alternatively

λ X: λ P: FORALL(X, λ x: x $\in$ $\bigcup^*$ (X, DISTRIBUTION(X, P)))

The semantic structure of rule (3) now is:

(3' non-wh) APPLY(PREDET', NPCENTRE')

After conversion this yields the same representation as (1' plural).

2.3.5 Wh-descriptions

Wh-determiners are classified as central determiners. This is primarily for semantic reasons, as wh-determiners plus a noun have the semantic function of determining the *source* of quantification. Definite descriptions consisting of a singular nominal and a wh-determiner ('which flight') must be treated by a distinct semantic rule:

> " Some determiners have *inherent* scope properties in that they always give rise to quantifications with wider (or narrower) scope than other quantifications and scope-bearing elements, such as negations. For instance, WH-determiners like 'which' and 'what' always have wide scope. " *(Bunt 1985:143)*

Bunt gives no treatment of singular or plural wh-descriptions; their representations are given in this section and in sections 2.3.6 and 2.3.7. There is a second, more imperative reason to introduce separate semantic rules, which is that a wh-phrase refers to the object that makes up the answer. The meaning of a question we take to be the *way* the correct answer can be computed. A semantic formula denoting the correct answer represents that way, because evaluation of the formula is a computation of the answer. Therefore, single wh-phrases are to be represented in terms of the ! operator and plural wh-phrases by the selection operator or by one of the other set-denoting operators.

A wh-description denotes **the object** which forms the answer. For example, 'Which plane is due' is represented as:

$!$(SELECT(Planes, Cr), λ x: Due(x))

This formula denotes the one plane that is due amongst the relevant ones. Compare this with the semantic representation for 'The plane is due'. According to the syntactic and semantic rules (1) and (2), discussed in the previous paragraphs, the representation of the declarative sentence is:

APPLY(Due, $!$(Planes, Cr)).

This formula denotes a truth value. Note that both expressions refer to the current context and that in the first the $!$ operator has wide scope with respect to the representation 'Due' of the verb phrase.

As the semantics differs, singular wh-descriptions require different variants of the semantic rules (1') and (2'):

(1' singular, wh) λ P: $!$(NPCENTRE', λ x: P(x))

Consequently, the NPCENTRE for singular wh-descriptions denotes a set rather than a definite referent:

(2' singular, wh) SELECT(NOM', λ x: CENTRALDET'(x))

This turns out to be the same as for plural definite descriptions (see section 2.3.4, (2' plural)).

The representation of plural wh-phrases ('which planes') is like that of modified phrases ('planes tested by machines') (Bunt 1985:197-198, (9.6a)), because they both refer to a set of relevant objects. In the notation adopted here (see section 2.3.4), the representation of a plural wh-phrase like 'Which planes are due' is

$\bigcup$*(SELECT(Planes, Cr), DISTRIBUTION(SELECT(Planes, Cr), λ x: Due(x)))

In a single-noun phrase sentence, 'Which Xs' is about individual Xs: the question 'Which planes are due' is about individual planes (the elements of the source) and not about the way they are due (e.g. in squadrons), which is why the $\bigcup$* operator cannot be omitted. First a NPCENTRE is constructed with rule (2 plural), with semantic representation SELECT(Planes, Cr). From this, rule 1 (plural, wh) constructs the representation given above:

(1' plural, wh) λ P: $\cup$*(NPCENTRE', DISTRIBUTION(NPCENTRE', λ x: P(x)))

2.3.6 Multi-noun phrase sentences

I will not repeat the representation of multi-noun phrase sequences with only plural noun phrases (Bunt 1985:Ch. 8).
First I want to show that the representation of definite descriptions by the ! operator, as given in paragraph 2.3.3, perfectly expresses the semantics of noun phrase sequences. The 'noun phrase sequence' is a syntactic structure of which the semantic part represents *the sequence of all arguments of a verb.* This ordered list of noun phrase representations is useful in generating scope variants.

> " The relative scopes of the quantifications correspond in this approach to the order of the NPs in the noun phrase sequence; readings with relative scopes that deviate from the order of the NPs in the sequence can be constructed by generating permutations of the noun phrase sequence." (Bunt 1985:149).

Moreover, I will give a semantic variant for multi-noun phrase sentences where the noun phrases have no explicit quantifiers and have equally wide scope. An example is 'These people give the children those books'. The preferred reading of these sentences is called *cumulative* (Bunt 1985:144). Third, I want to show that a noun phrase sequence also applies to the representation of multi-noun phrases , when combined with one plural wh-noun phrase (as treated in the previous section).

A sequence of two singular definite noun phrases

For singular noun phrases sentences, no distributional aspects of quantification are involved in the representations.
The rule that generates a sequence of two noun phrases, functioning as verb arguments, is

(6) NP1 + NP2 → NPS

The semantic part of this rule has several variants, corresponding to different scope orderings and assignment of grammatical functions. For left-to-right scope ordering and subject preceding direct object, we have:

(6') λ R: (NP1'(λ x1: NP2'(λ x2: R(x1, x2))))

Note that this rule applies to a sentence like 'John loves Mary'.

Take the sentence 'The dog barks at the cat'. According to rules (1') and (2') the definite descriptions generated are:

λ P: P(!(Dog, Cr))

λ Q: Q(!(Cat, Cr))

Suppose the predicate 'Bark' has already been converted. Then the argument of the first noun phrase representation in (6') is:

(6A) λ x1: NP2'(λ x2: Bark(x1, x2))

Substitution of the two noun phrase representations gives:

λ P: P(!(Dog, Cr) [λ x1: λ Q: Q(!(Cat, Cr) [λ x2: Bark(x1, x2)]]

Repeated lambda-conversion simplifies this to:

Bark(!(Dog, Cr), !(Cat, Cr))

A sequence of cumulative noun phrases

The cumulative reading occurs, when several noun phrases have quantifications with equally wide scope, as in 'Three boys kissed three girls'. On this reading, the number of boys involved is three and the number of girls involved is three. This reading cannot be generated by rule (6) for two reasons, one semantic and one technical.

Firstly, rule (6') assigns wide scope to the first NP, resulting in the reading where *each* of the boys kissed three girls. That is, rule (6') assigns to the second (and third) noun phrase the so-called *local source involvement* reading of the numeral quantifier (Bunt 1985:143). This is not the preferred reading here.

Secondly, on the preferred reading, each set of involved persons has three elements. The representation expresses, for example, that the number of boys that kissed *at least* one girl is three. The correct representation includes an existential quantification over the set of girls and one over the set of boys. These existential quantifications cannot be constructed in this way, as the representations of the respective sources 'hide' inside the standard representations of the plural noun phrases, as defined by rule (1' plural).

For these reasons, Bunt introduces rules that form *cumulative noun phrases* from a numerical quantifier and a nominal constituent. Their representation is the pair consisting of the numeral 'three' and the representation of the source. The numeral and the representation denoting the source can subsequently be used by the rule that generates a noun phrase sequence with a cumulative reading.

Not only sentences with explicit numerical quantifiers have a cumulative reading. A sentence like 'These boys pushed the cars' has a preferred reading that is cumulative: all contextually relevant boys were involved and all contextually relevant cars were involved, but none of the two NPs has wider scope. In order to generate this reading, we must have a rule that lifts a noun phrase centre like 'these boys' to a cumulative noun phrase. The semantic representation is a pair consisting of the quantifier expressing complete involvement, and the quantification domain. But the example also shows that cumulative readings are not restricted to individual distribution. Therefore, the distribution function must generally be included in the semantic representation of cumulative noun phrases.

Here I will give semantic variants of rules (1) and (6), forming cumulative noun phrases and noun phrase sequences. A cumulative NP is represented as a pair, consisting of the quantifier indicating complete *source* involvement, and the representation of the quantification domain (the distributed, unrestricted source).

(1' plural , cum) TUPLE(

1: λ P: FORALL(NPCENTRE', λ x: x $\in$ $\bigcup^*$(
NPCENTRE', DISTRIBUTION(NPCENTRE', P)))
2: DISTRIBUTION(NPCENTRE', True))

(Where 'True' stands for the predicate 'λ x: TRUE', 'TRUE' being a constant denoting the truth value *true*.) The variant of rule (6) constructing cumulative noun phrase sequences, is formulated for any number of noun phrases. The subscripts 1 and 2 refer to the first and the second element of the semantic representation of cumulative noun phrases, as defined in (1' plural, cum) above.

(6' plural, n cum) CONJUNCTION(

1: λ R: NP1'$_1$(λ x1: EXIST(NP2'$_2$, λ x2: ... EXIST(
NPn'$_2$, λ xn: R(x1 ... xn)) ...))

$\vdots$

i: λ R: NPi'$_1$(λ xi: EXIST (NP1'$_2$, λ x1: ... EXIST(
NP(i-1)'$_2$, λ x(i-1): EXIST(NP(i+1)'$_2$, λ x(i+1): ...
EXIST(NPn'$_2$, λ xn: R(x1 ... xn)) ...)) ...))

$\vdots$

n: λ R: NPn'$_1$(λ xn: EXIST(NP1'$_2$, λ x1: ... EXIST(
NP(n-1)'$_2$, λ x(n-1): R(x1 ... xn)) ...)))

Each conjunct represents the total involvement of one NP in a minimal way: all elements of the source denoted by this NP are involved with at least one element of each of the sources denoted by the other NPs. For example, (1' plural, cum) and (6', plural, n cum) generate the following representation for the cumulative reading of the sentence 'These people gave the children those

books'. I have used a shorter standard notation to increase readability. The logical constant 'SELECT' is writen as { ... }, 'FORALL' and 'EXIST' as $\forall$ and $\exists$, and 'DISTRIBUTION' as δ.
The representation is: CONJUNCTION(

1: $\forall$({People, Cr}, λ x: x $\in$ $\bigcup$*({People, Cr}, δ({People, Cr}, λ x1: $\exists$(δ({Children, Cr}, λ x2: $\exists$(δ({Books, Cr}, λ x3: GIVE(x1, x2, x3))))))))

2: $\forall$ ({Children, Cr}, λ x: x $\in$ $\bigcup$*({Children, Cr}, δ({Children, Cr}, λ x2: $\exists$(δ({People, Cr}, λ x1: $\exists$(δ({Books, Cr}, λ x3: GIVE(x1, x2, x3))))))))

3: $\forall$({Books, Cr}, λ x: x $\in$ $\bigcup$*({Books, Cr}, δ({Books, Cr}, λ x3: $\exists$(δ({People,CR}, λ x1: $\exists$(δ({Children, Cr}, λ x2: GIVE(x1, x2, x3)))))))))

A sequence with one wh-noun phrase

Rule (6) does not apply to multi-noun phrase sentences with one wh-noun phrase. If the wh-phrase is the first in the sentence, as in 'Which books did these girls give to the children', rule (6) assigns wide scope to it, which is correct. However, the standard representation of 'these girls' and 'the children' introduces a universal quantification over the sources. As a result, applying rule (6) gives a representation denoting only those books given by *each* girl to *all* children (the reading with local involvements.

The preferred reading of this example is cumulative with respect to all but the first noun phrase, to which global scope is assigned. That is, except for the wh-noun phrase, all noun phrases have equally wide scope.

One straight-forward way to generate this reading is to combine a wh-phrase with a cumulative noun phrase sequence, as defined above, by applying the wh-phrase representation to the cumulative representation.

However, this results in a reading that denotes the empty set if one of the children did not get a book or one of the books was not given: the corresponding conjunct would denote 'false' as its universal quantification is falsified.

Of course, this is also true of the reading that assigns local involvements. It is even true for sentences *without* a wh-phrase, like 'These people give those books to the children', when analysed according to rule (6), with a left-right order of scopes. The problem with these sentences is that they must be interpreted in the light of current focus and topic.

Although the universal involvements are part of the semantics of the sentence, from a *pragmatic point of view* they are less important, compared to 'wh-involvement'. For sentences with one wh-phrase, it is therefore reasonable to settle the matter as follows. The cumulative representation of the other noun phrases is regarded as a *presupposition*, while the semantic representation expresses wh-source involvement. This involvement is kept 'minimal', in the sense that each element of the wh-quantification domain is involved with at least one element of each of the other domains. For the representation of presuppositions in a phrase structure grammar, see Dols (1990a). Here, I give only the semantic variant of rule (6), where n, m $\geq$ 0, and the wh-noun phrase is called 'WH-NP'.

(6' plural, n cum, wh, m cum) λ R: APPLY(
WH-NP', λ y: EXIST(NP1'$_2$, λ x1: ... EXIST(
NP(n+m)'$_2$, λ x(n+m):
R(PERM(y, x1 ... x(n+m)))) ...))

The operator PERM permutes the arguments of the relation that involves the sources. The correct permutations depend upon the definition of the semantic types of the arguments and the type of the relation R.. A wh-phrase always has wide scope, even if its role in the involvement is not the first. The permutation makes sure that all possibilities are generated. For example, in 'Which books gave these people to the children', n is 0, m is 2, and permutation (x1, y, x2) is the correct one. Permutation is also needed if all phrases including the wh-phrase are in their 'natural' position with respect to the relation 'R'. For example, in 'These planes come from *which cities*?' (which is only correct with strong emphasis on the wh-noun phrase which yields the so-called 'echo-question' interpretation), n is 1, m is 0, and the permutation (x1, y) is the correct one.

2.3.7 Multi-wh-noun phrase sentences

The preferred reading of sentences with more wh-phrases like 'Which plane comes from which city' or 'Which planes come from which cities', is cumulative, as all noun phrases have equally wide scope. The answer to such questions consists of a *list* of representations that denote the answer to the individual wh-phrases. For the first sentence this is the pair consisting of representations denoting a plane and a city. For the second sentence, the pair consisting of the set of planes and the set of cities from which they are from, is not very informative because the precise relation between planes and cities is not represented. A better representation would be a single set consisting of the pairs of related planes and cities.

Singular wh-phrases may also be interpreted in a plural way, indicating individual distribution. The sentence 'Which plane comes from which city' may be interpreted as a question about all planes and all cities such that a plane comes from a city. This interpretation expresses the distributive reading of the second sentence above, which is why I do not consider it further here.

I will first give rules for the representation of sequences consisting of only singular wh-phrases and then rules for sequences with only plural wh-phrases. Rules for combining singular and plural wh-phrases are not given, but they can be formulated fairly easily on the bases of the rules below.

A sequence of two singular wh-noun phrases

For the sentence 'Which plane comes from which city' the rule (6' singular, 2 wh) generates a pair consisting of the representations for the plane and the city involved, but only, if there is exactly one of each. How these two presuppositions are represented and dealt with, is explained in Dols (1990a). We have seen in section 2.3.5 that the representations for the two wh-phrases according to the rules (1' singular, wh) and (2' singular, wh) are:

λ P: !(SELECT(Planes, Cr), λ x: P(x))

and

λ Q: !(SELECT(Cities, Cr), λ x: Q(x)).

It is not possible to use rule (6') to generate a 'noun-phrase sequence' for these two noun phrases, because it assigns global scope to the first whereas both wh-phrases have equal scope. A second problem is that circularity must be avoided, because the plane involved is characterized by a predicate P, which says that it comes from a city characterized by a predicate Q that in its turn refers to the plane ...etc. The following semantic variant of (6) does the job.

(6' singular, 2 wh) λ R: TUPLE(
1: NP1'(λ x1: R(x1, NP2'(λ x2: R(x1, x2)))),
2: NP2'(λ x1: R(NP1'(λ x2: R(x2, x1)))), x1)))

Application of this rule will after conversion and after application to a verb representation give:

TUPLE(1: ! (SELECT(Planes, Cr), λ x1: From(x1,
!(SELECT(Cities, Cr), λ x2: From(x1, x2)))),
2: !(SELECT(Cities, Cr), λ x1:
From(!(SELECT(Planes, Cr), λ x2: From(x2, x1)))))

This denotes *the* pair of *a* plane and *a* city such that the first comes from the second.

A sequence of two plural wh-noun phrases

I will give two ways of representing sentences with more than one plural wh-noun phrase. The first is interesting, because it shows that standard representations for wh-noun phrases suffice. That is, cumulative variants of wh-noun phrases are not needed. The second is more appropriate with respect to the generation of an answer.

The first reading for sentences with two wh-noun phrases is represented by the pair consisting of both the sets of involved planes and cities. The semantic representation is as follows, where each wh-noun phrase is generated by rule (1' plural, wh), as explained in section 2.3.5.

λ **R: TUPLE(**

1: NP1'(λ x1: EXIST(NP2'(λ x2: R(x1, x2)), True))

2: NP2'(λ x1: EXIST(NP1'(λ x2: R(x1, x2)), True))

Each element of this pair denotes the global involvement of one of the wh-noun phrases. Thus, this representation answers each of the wh-questions in isolation.

As this is not very informative, I propose a different solution (even semantics is not autonomous). It is mentioned in the beginning of this section that the phrase 'Which planes come from which cities' should be analysed as denoting the set of pairs of planes and cities involved. The resulting set of pairs shows which planes and cities are related.
In order to produce the correct Cartesian product that contains the pairs, the ***quantification domains*** of the noun phrases are needed. Therefore, a variant of rule (1) is proposed, that lifts the NPCENTRE to a cumulative NP, denoting the distributed, unrestricted source:

(1' plural, wh, cum) DISTRIBUTION(NPCENTRE', True)

Rule (6' plural, wh, cum) generates the correct representation. To denote the involved subset of the Cartesian product is *over-informative*, as the specific distribution is part of it. Therefore, the *global* involvements are constructed by applying the $\bigcup^*$ operator (see section 2.3.4) through iteration. ELTi denotes the i-th element of a tuple.

(6' plural, 2 wh)

λ **R: ITERATE(SELECT(** $\times$ **(NP1', NP2'),** λ **x: R(x)),**

λ **x: TUPLE(1:** $\bigcup^*$**(ELT1(x)), 2:** $\bigcup^*$**(ELT2(x)))**

Applied to the example 'Which planes come from which cities', this formula denotes the set of pairs of which the first element denotes the set of all all planes that (in one way or another) come from the one member of the second element, which denotes a city. This second element of each pair may generally be a set of many elements, depending upon the distribution of the particular predicate.

2.3.8 Rigid designators

Proper names are a special kind of descriptions which always denote the same individual (Kripke 1972). Therefore, proper names are usually called *rigid designators*. Some proper names cannot be combined with determiners (*the John) but others should, as in 'the Kl402'.

A definite description like 'the plane' may denote different objects during the course of a dialogue, but the denotation of a proper name like 'John' or 'Kl402' is fixed. It is for this reason that the function constant 'Cr', which chooses the most relevant denotation from the current context, is not taken into account in the semantic structure that is associated with the rule that combines a central determiner and a proper name. The representation of a unique description like 'the Kl402' thus does not refer to the context.

Rigid designators are problematic when combined with propositional attitudes. Suppose that the proper names John and Jan both denote the same individual according to a given interpretation. If A believes that John is John it need not be the case that also A believes that John is Jan.

In an intensional, possible worlds analysis, these problems are explained and solved (Moore 1984:20-28). In this paper, only extensional representations are considered. I do think that an extensional solution to this problem must take knowledge of the language into account. Speakers must be assumed to have partial knowledge of the language they speak. If a speaker does not *know* or *believe* that the denotation of both proper names is the same then the inference should be blocked. Instead of blocking, a *default inference* that can be withdrawn, is also acceptable. Blocking the truth of the inference in a model-theoretic analysis of utterances in dialogues can be achieved by assigning *default* valuations to the constants of a language *relative to the users* of that language and by representing the valuation as part of the knowledge of the dialogue partners. Thus, an interpreter believes that the partner believes that John is Jan, only if this information is extracted from explicit communication. Or, an interpreter (if he believes that John is Jan) may suppose that, by default, the partner also believes that John is Jan.

3 A comparison with some other solutions

The solutions of Frege, Russell and Strawson for problems with definite descriptions are dominant in the literature. It is relevant to consider the respective solutions in more detail. In this paper, I introduce a bounded uniqueness operator in a semantic representation language. Semantic representations, expressed in this language, are generated by phrase structure rules for natural language sentences. In particular, representations are given for sentences containing unique and definite descriptions, including wh-noun phrases. Both the grammar formalism and the representation language constitute important parts of the TENDUM dialogue system (Bunt et al. 1984). It is interesting to see how the solutions of Frege, Russell and Strawson relate to the proposals in section 2, and to the treatment in the TENDUM system.

3.1 The solutions of Frege, Russell and Strawson

In section 2 I have explained that two presupositions are associated with unique and definite descripitons. The first expresses that there is only one referent, the second expresses that there is at least one.
Both Frege and Russell propose descriptions that denote 'false', when uniqueness or existence of the referent are not satisfied.

Russell formalizes the presuppositions, and incorporates them in the semantic representation of the sentence containing the description. As a result, failure of these presuppositions causes the proposition that represents the sentence to be false. For example, the sentence 'the king of France is bald' is represented as
$\exists$ **x: [BALD(x) $\wedge$ KING-OF-FRANCE(x) $\wedge$ $\forall$ y:**
KING-OF-FRANCE(y) $\rightarrow$ y = x].
The existence presupposition is formalized in terms of the *existential* quantification, while the uniqueness presupposition is expressed by the *universally* quantified conjunct.

Frege introduces a set-denoting operator *iota* and an operator \. The second operator may be applied to a set expression. In case that expression denotes a singleton set, the operator takes the unary element, else it denotes that set (van Eijck 1985:38). The *iota* operator introduces a variable and denotes the set of all objects that satisfy a predicate. It is a syntactic variant of SELECT(x, F(x)), which denotes the set of objects for which the predicate F holds. Used together, the *iota* and \ operators either denote a plural set or the element of a singleton set. For example, iota(x, King-of-France(x) ∧ Bald(x)) denotes the set of *all* bald kings of France. And \ (iota(x, King-of-France(x) ∧ Bold(x))) denotes *the* king of France, if there is exactly one.

Frege's solution is problematic in a typed language, because syntactic correctness of an expression containing a combination of the *iota* and \ operator does not guarantee interpretability. For example, the expression Due(\(iota(x, Plane(x) ∧ From(x, Montreal))), 12:00), represents 'the plane from Montreal is due at 12 o'clock'. When there are two planes from Montreal, or none at all, the first argument of the function Due will be a set. As the function Due maps *singular* planes to truthvalues, the resulting expression is semantically anomalous. According to van Eijck, Frege's solution is satisfactory within his own formalism, as he uses functions that are applicable to any object. They give the value 'false' when applied to 'unintended' arguments.

In the first part of this paper I explained that an operator for unique descriptions must either denote an object of the correct type, or have no denotation at all, in which case the control mechanism of the dialogue system takes over. The first to propose such a solution in the literature was Strawson (Strawson 1950), although not in the context of dialogue systems (in the same volume of *Mind* Turing wrote *avant la lettre* about intelligent systems... (Turing 1950)).

Strawson introduces the idea of presuppositions for definite descriptions. When they fail to be true, a sentence containing the definite description has no denotation at all. He accepts that the denotation of a definite description is undefined when the presupposition is not satisfied. He explains the difference between expressions and utterances denoting a unique referent. An expression always has a

meaning, defined in terms of the way the referent is 'computed' from the current context; but an utterance sometimes does not refer, for example, when the rules for determining the referent are applied to a situation where no ***unique*** referent exists. He explains this with the term 'I' of which the meaning is defined in terms of identifying the speaker. The fact that it has a unique referent when ***used*** is not part of its meaning.

> " Meaning (...) is a function of the sentence or expression; mentioning and referring and truth or falsity are functions of the use of the sentence or expression. (...) to give the meaning of a sentence is to give *general directions* for its use in making true or false assertions." *(Strawson 1950, p. 327)*

The ***use*** of a unique or definite description, like 'the table', presumes that there is some individual as specified, and that the context of use will sufficiently determine which one:

> " But to use "the" in this way is not to *state* that those conditions are fulfilled. (...) to use the sentence is not to assert, but it is (in the special sense discussed) to imply, that there is only one thing which is *both* of the kind specified *i.e.* a table *and is being referred to* by the speaker." *(Strawson 1950:333)*

Indeed, it is important to realize that presuppositions pertaining to an utterance should not be treated as being part of the current topic. An informative utterance of which the content is not consistent with the beliefs of the interpreter, will in general give rise to a discussion of the disagreements involved. But the apparent presuppositions of an utterance will in general be accepted as information about the beliefs of the speaker. The belief systems of dialogue partners need not be consistent together, and the partners need not strive for agreement on all aspects. Having diversing information concerning the context is not a sufficient reason to discuss matters. Each partner must decide whether and when divergent information should be discussed or not. The rules that regulate such a decision are unknown, and a discussion is outside the scope of this paper.

3.2 Descriptions in the TENDUM dialogue system

The Dutch definite articles in the lexicon of the TENDUM system are DE (THE), DAT (THAT), DIE (THAT, THOSE), DEZE (THIS, THESE), DIT (THIS neuter), HET (THE singular, neuter), WELK (WHICH singular, neuter), WELKE (WHICH singular, non-neuter, WHICH plural). Their semantic representation consists of the function constant Cr (see section 2.2).

For sentences with singular definite descriptions, the grammar component of the TENDUM dialogue system includes rule (2) forming a NPCENTRE and rule (1) that lifts a NPCENTRE to a NP (section 2.3.1).

In the TENDUM dialogue system, the semantic representations for singular definite descriptions incorporate the existence and uniqueness presuppositions.

Rule (2') in the TENDUM dialogue system is as follows. The semantic structure of a plural as well as a singular NPCENTRE consists of a set-denoting expression, representing the noun, which is restricted to the contextually relevant elements. For example, the representation for the NPCENTREs of *both* 'the plane' and 'the planes' denotes a set:

(2') SELECT(Planes, λ x: Cr(x))

If the presupposition pertaining to the (use of the) definite article is satisfied, this representation denotes the singleton set consisting of only the unique referent. This is unsatisfactory, because applying a predicate to a *set* will in general yield an expression that is not interpretable. I explained this point before, when discussing Frege's solution.

In the TENDUM dialogue system this problem is solved in the following way. Semantic rule (1') introduces a universal quantification over the singleton set. The semantic representation for a sentence like 'the flight is due' thus is

$\forall$ **(SELECT (Planes, Cr), λ x: Due(x))**

Abstraction over the predicate Due results in

λ P: $\forall$ (SELECT(Planes, Cr), λ x: P(x))

In this way, the predicate P is applied to the unique element, if there is one. In order to account for the presupposition, this function is conditionalized in the following way: if the presupposition is satisfied, i.e. the set of objects referred to is a singleton set, the denotation is defined in terms of the universal quantification, else the value 'FALSE' is denoted. The condition is constructed from a logical constant CONDITION, that relates three constituents, of which the role in the relation is indicated by 'if', 'then' and 'else'. For example, 'this plane is due' is represented by an application of

(1' singular) λ P: CONDITION(
if: COUNT((SELECT(Planes, Cr)) == ONE
then: $\forall$ (SELECT (planes, Cr), λ x: P(x))
else: FALSE)

to the representation of the verb phrase Due. This yields after conversion the condition expression.

As wh-expressions denote the definite referent that forms the answer, the rule that lifts a NP to a NPCENTRE has a semantic variant. The semantic structure assigned to phrases like 'which plane' is as follows.

(1' singular, wh)

$$
\begin{array}{l}
\lambda\ \mathbf{P}\text{: }\mathbf{CONDITION(} \\
\mathbf{if}\text{: }\mathbf{COUNT(\ SELECT(\ SELECT(\ Planes,\ Cr),} \\
\qquad\qquad\qquad\qquad \lambda\ \mathbf{x}\text{: }\mathbf{P(x)\ ))\ ==\ ONE} \\
\mathbf{then}\text{: }\mathbf{SELECT(\ SELECT(\ Planes,\ Cr),\ }\lambda\ \mathbf{x}\text{: }\mathbf{P(x))} \\
\mathbf{else}\text{: }\mathbf{FALSE)}
\end{array}
$$

In this representation the expression SELECT(SELECT(Planes, Cr), λ x: P(x)) has two occurences, one to express the presupposition and one to denote the referent.

Note that, when the presupposition is satisfied, the expression denotes a *set*. It would be more appropriate to have a representation that denotes the unique element from that set, as the answer to a question is usually formed from the denotation of the question. In section 2, I have given representations for wh-noun phrases that does denote the referent that forms the answer to the question.

The representation of unique and definite descriptions in the TENDUM system is essentially that of Russell, but it also borrows from Frege's solution.

As in Russell's solution, the uniqueness and existence properties are part of the semantic representation. As in Frege's solution, the representation is a function of a set-denoting constituent. By contrast, in the TENDUM system the predicate is applied to the unique element through the use of a universal quantification, whereas Frege uses the sentential operator \ to denote the unique element.

If the presupposition is not satisfied, application of a predicate in Frege's system denotes 'false' by *default*, in the TENDUM system it denotes 'false' by *conditionalization* and in Russell's solution it denotes 'false' by *'conjunctionalization'*. In that situation, the negation of such expressions yields true, which is *very* unsatisfactory. It is awkward, because it causes a system to answer 'no' to the question 'Does the Dutch plane arrive on time?', when there is no such plane at all. Thus, the answer confirms in an implicit way the false presupposition that there is such a plane.

At the one hand, the inclusion of the presupposition as part of the semantic representation makes sure that the latter has a denotation when there is no unique element. At the other hand, this results in a wrong or uncooperative answer to affirmative as well as negative questions. Once it is accepted that expressions need not always have a denotation, there is no need to include the presuppositions in the representation and the awkward side effect of uncooperative reactions disappears.

The solution presented in section 2 is based upon the idea that there is no need to make sure that there is always a referent. When according to the system there is no referent, the system should be able to report the conflicting situation. The system accepts in a way, that there is no referent *according to its knowledge*. This is also the kernel of Strawson's solution as explained above. This solution only works if the system is able to detect a failing presupposition. Therefore, the presuppositions must be represented in one way or another. It is feasible to generate presuppositions parallel to the semantic representations, by extending phrase structure rules with a presupposition part. This part specifies how presuppositions are constructed from semantic representations of constituent phrases together with their corresponding presupposition abstractions (Dols 1990a).

4 Summary

In the Tendum dialogue system a Frege-Russellean semantics is implemented that includes representations of presuppositions in the semantic structure. In this paper we have presented semantic rules based upon the by now generally accepted solution first worded by Strawson. The representation also borrows from Frege's solution, as plural definite descriptions denote a set, whereas unique and singular definite descriptions denote the definite referent.
I have formulated

- a uniform treatment of singular unique and definite descriptions in terms of a *bounded uniqueness operator* in the context of a higher-order typed representation language
- examples, including multi-noun phrase sentences, showing that this treatment fits into a phrase structure analysis
- the proposal, that, in general, the preferred reading of multi-noun phrase sentences is *cumulative*, and rules that generate such cumulative semantic representations.
- semantic rules for sentences with one or more wh-noun phrases.

As the 'normal' representation for sentences with one or more wh-noun phrases is not very *informative*, I have formulated a representation that shows which of the entities that form the answer are related. However, this representation does not show *how* they are related, as this would be over-informative.

5 Summary of the grammar rules

The following list contains the grammar rules used in this paper. The numbering of the rules is the same as in the text. All rules consist of two parts: the syntactic phrase structure part and the semantic part. Aspects of attribute values and conditions on them were of minor or no concern. Those conditions that were of concern are incorporated as part of the numbering system. The global condition part, the local condition part, the carry-over part and the new attributes part are not mentioned.
In Dols (1990) I have defined a new part for these rules, that generates representations for presuppositions. The advantage is, that such presuppositions have no effect on the truth conditions of the semantic representations.

Rule 1

(1)

NPCENTRE → NP

(1' singular)

λ P: APPLICATION(P, NPCENTRE')

(1' singular, wh)

λ P: !(NPCENTRE', λ x: P(x))

(1' plural)

λ P: (FORALL(NPCENTRE', λ x: x ∈ ⋃*(NPCENTRE', DISTRIBUTION(NPCENTRE', P)))

(1' plural, cum)

TUPLE(1: λ P: FORALL(NPCENTRE', λ x: x ∈ ⋃*(NPCENTRE', DISTRIBUTION(NPCENTRE', P))) 2: DISTRIBUTION(NPCENTRE', True))

(1' plural, wh)

λ P: ⋃*(NPCENTRE', DISTRIBUTION(NPCENTRE', λ x: P(x)))

(1' plural, wh, cum)

DISTRIBUTION(NPCENTRE', True)

Rule 2

(2)

CENTRALDET + NOM → NPCENTRE

(2' singular)

!(NOM', λ x: CENTRALDET'(x))

(2' singular, wh)

SELECT(NOM', λ x: CENTRALDET'(x))

(2' plural)

SELECT(NOM', λ x: CENTRALDET'(x))

Rule 3

(3)

PREDET + NPCENTRE → NP

(3' non-wh)

APPLICATION(PREDET', NPCENTRE')

Rule 4

(4)

PROPERNAME → NP

(4')

λ P: APPLICATION(P, PROPERNAME')

Rule 5

(5)

CENTRALDET + PROPERNAME → NP

(5')

λ P: APPLICATION(P, PROPERNAME')

Rule 6

(6)

NP1 + NP2 → NPS

(6')

λ R: (NP1'(λ x1: NP2'(λ x2: R(x1, x2))))

(6' singular, 2 wh)

λ R: TUPLE(1: NP1'(λ x1: R(x1, NP2'(λ x2: R(x1, x2)))), 2: NP2'(λ x1: R(NP1'(λ x2: R(x2, x1)))), x1)))

(6' plural, n cum)

CONJUNCTION(

1: λ R: NP1'$_1$(λ x1: EXIST(NP2'$_2$, λ x2: ... EXIST(NPn'$_2$, λ xn: R(x1 ... xn)) ...))

⋮

i: λ R: NPi'$_1$(λ xi: EXIST(NP1'$_2$, λ x2: ... EXIST(NP(i-1)'$_2$, λ x(i-1): EXIST(NP(i+1)'$_2$, λ x(i+1): ... EXIST(NPn'$_2$, λ xn: R(x1 ... xn)) ...)) ...))

⋮

n: λ R: NPn'$_1$(λ xn: EXIST(NP1'$_2$, λ x1: ... EXIST(NP(n-1)'$_2$, λ x(n-1): R(x1 ... xn)) ...)))

(6' plural, n cum, wh, m cum)

λ R: APPLICATION(WH-NP', λ y: EXIST(NP1'$_2$, λ x1: ... EXIST(NP(n+m)'$_2$, λ x(+1)n: R(PERM(y, x1 ... x(n+m)))

(6' plural, 2 wh)

λ P: ITERATE(SELECT($\times$(NP1', NP2'), λ x: P(x)), λ x: TUPLE(1: $\bigcup^*$(ELT1(x)), 2: $\bigcup^*$(ELT2(x)))

6 References

Bunt, H.C. (1985) *Mass Terms and Model-theoretic Semantics.* Cambridge University Press.

Bunt, H.C. (1988a) On-line Interpretation in Speech Understanding and Dialogue Systems. In: *Niemann, H. and Sagerer, G. (eds.) Recent advances in Speech Understanding and Dialogue Systems.* Springer Verlag, Berlin.

Bunt, H.C. (1988b) DPSG and its use in sentence generation from meaning representations. In: *Zock, M, & Sabah, G. (eds.) Advances in Natural Language Generation.* Pinter Publishers, London.

Bunt, H.C., Beun, R.J., Dols, F.J.H., van der Linden, J.A., and thoe Schwarzenberg, G.O. (1984) The TENDUM Dialogue System and its Theoretical Basis. In: *IPO Annual Progress Report 19.*

Bunt, H.C., Thesing, J.C., Sloot, K. van der (1987) Discontinuous constituents in trees, rules and parsing. In: *Proceedings of the Third ACL/Europe Conference.* Copenhagen.

Dols, F.J.H. (1990a) Pragmatics of postdeterminers, non-restrictive modifications and wh-phrases. In: *Pragmatics in Artificial Intelligence*, Proceedings of the Fifth Rocky Mountains Conference on Artificial Intelligence (RMCAI-90), June 1990, New Mexico State University, Las Cruces, New Mexico, USA. A revised version of this paper can be found in: ITK Research Report no. 21, Institute for Language Technology and Artificial Intelligence, P.O. Box 90153, 5000 LE Tilburg, The Netherlands.

Dols, F.J.H. (1990b) *A Dialogue Referent Component in a Phrase Structure Grammar.* ITK Research report 22, Institute for Language Technology and Artificial Intelligence, P.O. Box 90153, 5000 LE Tilburg, The Netherlands. A revised version will appear in: *Dols, F.J.H. (ed.) (1990) Pragmatics in Grammar* (working title). Contributions from the 2nd International Pragmatic Conference, December 1989, University of Silesia, Katowice, Poland. Tilburg University Press, P.O. Box 90153, 5000 LE Tilburg, The Netherlands.

Eijck, J. van (1985) *Aspects of Quantification in Natural Language.* Dissertation, University of Groningen.

Gamut, L.T.F. (1982) *Logica, Taal en Betekenis II.* Aula-paperback 77, uitgeverij Het Spectrum.

Hilbert, D. and Bernays, P. (1970) *Grundlagen de Mathematik II.* Springer Verlag.

Kripke, S. (1972) Naming and Necessity. In: *Davidson, D. and Harman, G. (eds.) Semantics of Natural Language.* Reidel, Dordrecht.

Moore, R.C. (1984) A Formal Theory of Knowledge and Action. Technical Note 320, SRI International, Menlo Park, California. (also in: *Hobbs, J.R., and Moore, R.C. (eds.) Formal Theories of the Commonsense World.* Ablex Publishing Corp., Norwood, New Yersey, 1984.)

Sterling, L. and Shapiro, E. (1986) *The Art of Prolog, Advanced Programming Techniques.* The MIT Press, Cambridge, Masachusetts.

Strawson, P.F. (1950) On Referring. In: *Mind 59, Januari 1950, 330-344.*

Turing, A.M. (1950) Computing Machinery and Intelligence. In: *Mind 59, October 1950.*

Winston, P.H., Horn, B.K.P. (1984) *Lisp.* Addison-Wesley Publishing Company, Reading, Massachusetts, second edition.

ITK: P.O. BOX 90153 5000 LE TILBURG THE NETHERLANDS